STOCK ASSESSMENT OF PACIFIC MACKEREL (*SCOMBER JAPONICUS*) WITH RECOMMENDATIONS FOR THE 2003-2004 MANAGEMENT SEASON

EXECUTIVE SUMMARY

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by

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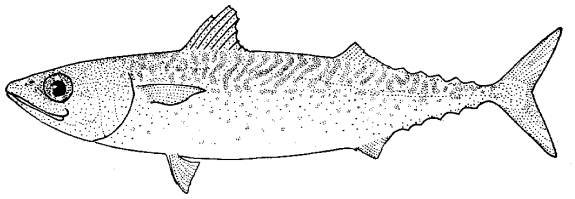

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INTRODUCTION

The following summarizes stock assessment results and harvest guideline (HG) recommendations for Pacific mackerel (*Scomber japonicus*) developed for the Pacific Fishery Management Council's (PFMC) management season of July 1, 2003 to June 30, 2004. This summary will also be included in the PFMC's Stock Assessment and Fishery Evaluation (SAFE) report for coastal pelagic species (CPS), and will be distributed prior to the June 2003 PFMC meeting. A comprehensive stock assessment report will be developed in spring 2004 when the PFMC's first formal stock assessment review (STAR) for this species will be conducted.

SUMMARY OF THE 2002-2003 FISHING SEASON

The coast-wide harvest of Pacific mackerel increased slightly (3%) in calendar year 2002 (Table 2). The directed fisheries off California and northern Baja California (Ensenada, Mexico) had a combined yield of 12,775 mt, compared to 12,424 mt in 2001. California's directed fishery for calendar year 2002 landed 4,536 mt – a drop of about 42% from the 2001 yield. The Ensenada fishery experienced a 95% increase in yield, from 4,078 mt in 2001 to 7,963 mt in 2002 (García and Sánchez 2003). The RecFIN estimate of recreational take was 276 mt in 2002, down from 561 mt in 2001.

The U.S. commercial fishery was provided a 12,535 mt HG for the 2002-2003 (July-June) season based on a July 1, 2002 biomass forecast of 77,892 mt (Hill et al. 2002). Through the PFMC management process, it was determined that in order to stay within the HG, there would be an initial directed fishery of 9,500 mt, with 3,035 mt set aside for incidental catch in other CPS fisheries. The 2002-2003 season has progressed slowly, with only 3,378 mt of the directed HG allocation being landed from July 2002 through April 2003. The directed fishery will likely remain open through June 30, 2003.

Some members of southern California's fishing industry attribute the slow season to poor availability rather than market demand. The same has been stated for the Ensenada fishery (Walterio Garcia-Franco, INP Ensenada, pers comm), which typically harvests larger yields when the fish are available. Little is known about mackerel abundance south of Ensenada, but spawning activity has historically been centered off the central and northern Baja California coast. Pacific mackerel have been present as incidental catch in whiting and salmon fisheries off Oregon and Washington since 1992. Mackerel catches in northern waters usually increase during El Niño events, and the presence of older and larger mackerel in the region may explain the relative paucity of older mackerel (ages $3) in the southern California catch. Sardine fishermen in the Pacific Northwest encountered 'catchable' quantities (i.e., pure schools) of mackerel through summer 2002.

ASSESSMENT METHODS

Model

A modified virtual population analysis (VPA) stock assessment model ('ADEPT,' Jacobson 1993), based on Gavaris' (1988) ADAPT procedure, was used to estimate biomass of Pacific mackerel. The ADEPT model has been used to assess Pacific mackerel for the past ten years and is described in detail in Jacobson (1993), Jacobson et al. (1994), and Hill et al. (1999a,b). Conventional VPAs back-calculate age-structured abundance utilizing catch-at-age and weight-at-age data, as well as assumptions regarding both age-specific natural mortality in each year of the time series and fishing mortality (F) estimates for the most recent year (referred to as 'terminal F'). The ADEPT model improves upon a conventional VPA by evaluating terminal F and other parameters to obtain the best statistical fit between VPA output and survey indices of relative abundance. The crux of the statistical procedure lies in the model's ability to estimate terminal F based upon the survey indices, using them to adjust the conventional VPA output.

The ADEPT model uses a standard suite of subroutines to estimate parameters in a VPA model using the simplex algorithm and subroutine from Press et al. (1990) with minor modifications. The standard program for parameter estimation is similar to that described by Mittertreiner and Schnute (1985). The ADEPT approach is based on maximum likelihood estimation algorithms. Parameters are estimated by minimizing an objective function which, in the case of ADEPT, is the negative log-likelihood of the data, given the model and parameter estimates (rather than the equivalent sums of squares used by Gavaris 1988). Two types of parameters are estimated in the ADEPT model: observation parameters (survey q's and exponents) and terminal F parameters. Observation parameters are used to interpret index data, which are used in turn to estimate terminal F parameters. Terminal F parameters are highly influential for estimating population

biomass for recent years. Natural mortality was assumed to be 0.5 yr^{-1} for all ages in all analyses (Parrish and MacCall 1978).

Data

The assessment model uses an annual time step and now incorporates 74 years (1929-2002) of fishery data, including landings (Table 2, Figure 1), age composition (Figure 2), and mean weights-at-age (Figure 3). Fishery data for the early historical period (1929-1965) were obtained from previously published assessments (Parrish and MacCall 1978; Prager and MacCall 1988). Abundance estimates from the VPA are adjusted by the model to better match trends in the survey data, which includes aerial spotter sightings (Lo et al. 1992; Figure 4), CalCOFI larval data (Figure 5), recreational fishery catch-per-unit-effort information (Figures 6 and 7), triennial shelf survey data (Figure 8), and power plant impingement rates (Figure 9). As in past assessments, component likelihoods for most surveys were weighted equally to a value of 1.0. The power plant impingement index (age-0 mackerel caught in cooling water at San Onofre Nuclear Generating Station) represents a relatively small portion of the coastline and was therefore down-weighted to 0.1. The ADEPT model can also accommodate weighted annual survey observations based on coefficients of variation (CVs) associated with the individual estimates. As per Hill et al. (2002), we calculated CVs for each survey observation and re-scaled them to a median value. Re-scaling CVs to a value of 1.0 had the benefit of maintaining equal weighting among surveys, while down-weighting annual observations within surveys for poorly-sampled or highly-variable years.

Fishing Mortality in the Terminal Year

The ADEPT model estimate of terminal F largely determines biomass estimates for the most recent years. Terminal F estimates for each age group were calculated using age-specific vulnerability parameters and a parameter for the overall fishing mortality rate:

$$[1] \quad F_a = V_a \bullet F \,,$$

where F_a is the fishing mortality rate at age a in the terminal year, V_a is the vulnerability for age a, and F is the fishing mortality rate experienced by fully recruited age groups (ages with V_a =1). The parameters F_a, V_a, and F were estimated after log transformation to improve statistical properties of the estimates. Vulnerability parameters in [1] could, in principle, be estimated individually by ADEPT or set manually to any fixed values based on 'prior' information. It is always desirable to estimate selectivities individually, however, data limitations often cause convergence problems making direct estimation impractical. When specified individually (fixed), the best that can be done is to estimate average vulnerability values by preliminary VPA analysis, then fix terminal selectivities to average values.

For this assessment, we enveloped uncertainty in recent biomass estimates by exploring a wide range of terminal year vulnerability scenarios. The default method, consistent with the previous two assessments (Hill et al. 2001 and 2002), was to use fixed age-specific parameters based on vulnerabilities averaged for prior years with catch-at-age similar to 2002 (i.e., large proportion of age 0 and 1 fish in the catch; see Figure 2). After an initial model run using fixed values, ADEPT was configured to estimate selectivities of age 0-3 fish individually (ages 4 and $5 were necessarily fully selected, i.e., V_a =1 for all model runs). The model converged, however, the parameter for age 2 fish was the only one estimated with any degree of certainty (CV=27%). Model estimates for age 0, 1, and 3 fish were similar to initial values from the default method, but CVs for the estimates were extremely high. We therefore used fixed values for 0, 1, and 3 year-old fish. Selectivities for age 0 fish are typically low (<0.2), and age 3 fish are moderately vulnerable to the fishery (roughly, 0.4-0.8).

A major area of uncertainty lies in the vulnerability of age-1 mackerel to the fishery. Age-1 vulnerability in the terminal year has the greatest potential impact on biomass calculations for recent most years. In other words, a high proportion of age 1 fish in the 2002 catch may be interpreted in two ways: assumed lower vulnerability equates to relatively higher abundance; or assumed higher vulnerability results in relatively lower abundance. Prior model estimates of age-1 vulnerability range from low (~0.2) to high (1.0), with no consistent pattern over the past fifteen years. For the final model run, we developed a broad range of 'states of nature' by calculating the frequency of occurrence of vulnerabilities for four general vulnerability categories (V_a=0.2, 0.4, 0.6, and 0.8) and subsequently, calculated an average vulnerability within each category. Ultimately, four model runs were conducted based on the age-1 vulnerabilities above and finally, these model outputs were used to derive a weighted estimate of important management stock parameters (e.g., biomass and recruits).

A summary of final V_a parameters is provided in Table 1.

Table 1. Age-specific vulnerability parameters applied in the final model run.

Age	Vulnerability Parameter (V_a)	Source
0	0.066	fixed average based on catch-at-age
1	0.209, 0.408, 0.602, 0.990	four values used to calculate weighted average
2	0.035	model est. (CV=27%)
3	0.722	fixed average based on catch-at-age
4 and \$5	1.000	fixed at 1

Biomass Projection

Biomass was estimated through the beginning of 2002 (calendar year), then a projected estimate of biomass for July 1, 2003 was calculated based on: 1) the number of mackerel estimated to comprise each year class at the beginning of 2002; 2) model estimates of fishing mortality during 2002; 3) assumptions for natural mortality (M=0.5) and F through the first half of 2003; and 4) mean weight-at-age for the terminal year. Weight-at-age data were used to convert numbers of fish to biomass for each age, which was summed across ages to obtain total (\$1 year-old fish) biomass.

RESULTS and DISCUSSION

The ADEPT model recalculates biomass and recruitment for all years in the 74-year time series. Differences in biomass estimates among assessment years can be caused by changes in landings, shifts in fishery age compositions, trends in fishery-independent surveys, and assumptions of terminal year fishing vulnerability. As is true for all age-structured population models, abundance-at-age estimates are the least certain for the most recent years when the youngest year classes have not yet become fully vulnerable to, or utilized by, the fishery. Compounding this uncertainty is the general lack of fishery or survey data for Pacific mackerel outside the Southern California Bight and the lack of fishery-independent information on recruitment. Catch-at-age and weight-at-age data have not yet been made available from the Ensenada fishery, which is comparable in volume to California's commercial fishery.

Biomass Trend

Pacific mackerel biomass peaked in 1982 at approximately 1.4 million mt, declining steadily to a low of 22,252 mt in 2000 (Table 3, Figure 13). The peak biomass observed twenty years ago was primarily built by exceptional year classes in 1978, 1980, and 1981 (Table 3, Figure 10). These recruitment pulses occurred after a decade of extremely low biomass from the mid-1960s to mid-1970s (Figure 13). The decline in biomass since 1982 has resulted from a steady decline in year class strength (Figure 10) and relatively low reproductive success (recruits per spawning stock biomass; Figure 11) since that time. Model estimates of 2000 and 2001 year class abundance are slightly higher than for the previous few years and recent reproductive success (recruits per spawning stock biomass) is more optimistic relative to the past 18 years.

The overall trend in \$1year-old biomass for the current assessment was similar to that estimated in the 2002 stock assessment (Hill et al. 2002). Compared to Hill et al. (2002), the biomass time series for the current assessment is 10% lower over the most recent decade. The current estimate of July 1, 2002 biomass is estimated to be 30% lower than last years' projection for that same time. A more precipitous decline in biomass was observed from 1997 to 2000. This decrease is attributed to relatively weak year classes in 1998 and 1999 (Figure 10), combined with high fishing mortality during the 1998 fishery. The 1998 fishery was the second largest on record (71,355 mt), with the majority (50,726 mt) of the total harvest being landed in Ensenada, Mexico (Table 2, Figure 1). Despite the lower overall estimates of biomass compared with Hill et al (2002), the current time series indicates a stabilization in biomass in the past two years (Figure 13). This may be attributed to what appears to be a relatively strong 2000 year class that contributes substantially to the exploitable biomass in 2002.

Biomass Projection

The July 1, 2003 biomass projection, used to calculate the 2003-2004 HG, was based on ADEPT outputs and certain assumptions about recruitment and fishing mortality during the first half of 2002. Estimates of year class strength (age-0 abundance) for the terminal year (2002) are included in the forecast. Various

approaches may be used to address uncertainty in model estimates of age-0 abundance: 1) use a model-derived estimate; 2) use an average of model-derived estimates; or 3) rely strictly on a stock-recruit relationship. Decisions concerning the best approach necessarily depend on assumptions regarding the accuracy of the hypothesized stock-recruit relationship and in particular, the existence of compensatory responses by the stock, i.e., relatively speaking, increased recruitment at low spawning biomass levels.

Reliance on the stock-recruit relationship seems reasonable when model estimates are considerably higher or lower than recently observed values and when no ancillary information exists to suggest that recruitment is atypically high (e.g., year class failure or a compensatory increase in juvenile production and/or survival). The model estimate of age-0 abundance for January 2002 was 337 million fish, well within the range of recruitments observed for the past seven years. Some evidence exists that suggests relatively strong year classes occurred in 2000 and 2001. The 2001 fishery contained the highest proportion of age-0 fish (2000 year class) in recent history (33%; Figure 2), in spite of market orders to not land smaller fish due to low oil content (Stephen Wertz, CDFG, pers comm). The 2000 year class comprised the largest proportion (63%) of the 2002 catch. Length data from recreational angler surveys indicated increased catches of young mackerel by 'shore mode' anglers in 2000 and 2001. Based on the above evidence for stronger 2000 and 2001 year classes, we applied the model estimate of 2002 age-0 abundance in the forecast. Finally, the projected estimate of July 1, 2003 population ($1 year-old fish) biomass was approximately 68,934 mt.

HARVEST GUIDELINE RECOMMENDATION FOR 2003-2004

In Amendment 8 to the CPS FMP (PFMC 1998), the recommended maximum sustainable yield control rule for Pacific mackerel was:

HARVEST = (BIOMASS-CUTOFF) x FRACTION x STOCK DISTRIBUTION ,

where HARVEST is the U.S. HG, CUTOFF (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, FRACTION (30%) is the fraction of biomass above CUTOFF that can be taken by fisheries, and STOCK DISTRIBUTION (70%) is the average fraction of total BIOMASS in U.S. waters. CUTOFF and FRACTION values applied in the Council's harvest policy for mackerel are based on analyses published by MacCall et al. (1985). BIOMASS (68,924 mt) is the estimated biomass of fish age 1 and older for the whole stock as of July 1, 2003. Based on this formula, the 2003-2004 season HG would be 10,652 mt (Table 4, Figure 14). The recommended HG is 1,883 mt lower (-15%) than the 2002-2003 HG, and lower than the average yield (~13,500 mt) realized by the fishery since the 1992-1993 season (Table 4).

ACKNOWLEDGMENTS

This annual stock assessment depends in large part on the diligent efforts of many colleagues and the timely receipt of their data products. Data were received in record time this year, and we hope to strive for this same goal in preparation for the STAR panel review in spring of 2004. Landings data from the Ensenada fishery were kindly provided by Walterio Garcia-Franco, INP-CRIP, Ensenada, Mexico. Port samples and a portion of the age data were provided by CDFG Marine Region personnel in Los Alamitos and Monterey with special thanks to Leeanne Laughlin, Valerie Taylor, Kelly O'Reilly, Travis Tanaka, Dianna Porzio, Tom Mason, Sonia Torres, Melissa Nugent for long dockside and laboratory hours. Wendy Dunlap (CDFG, Los Alamitos) supplied logbook data from California's CPFV logbook program. Ron Dotson, Amy Hays, and Sue Manion (NMFS, La Jolla) provided aerial spotter logbook data. Susan Jacobson (NMFS, La Jolla) extracted CalCOFI larval data. Numerous staff from SIO, NMFS, and CDFG assisted in the ongoing collection and identification of CalCOFI ichthyoplankton samples. Mark Wilkins (NMFS, Alaska Fishery Science Center, Seattle, WA) provided swept area estimates from the triennial trawl survey. Kevin Herbinson (Southern California Edison, Rosemead, CA) provided data on mackerel impingement at San Onofre Nuclear Generating Station.

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Table 2. Commercial and recreational landings (metric tons) of Pacific mackerel in California and northern Baja California (Ensenada, Mexico), for calendar years 1929 to 2002. See also Figure 1.

Year	CA Com.	CA Rec.	MX Com.	TOTAL	Year	CA Com.	CA Rec.	MX Com.	TOTAL
1929	26,297	134	0	26,431	1966	2,100	493	5,290	7,883
1930	7,499	134	0	7,632	1967	530	260	949	1,738
1931	6,466	134	0	6,600	1968	1,422	190	107	1,717
1932	5,658	134	0	5,792	1969	1,070	288	201	1,559
1933	31,576	134	0	31,711	1970	282	311	0	593
1934	51,641	134	0	51,775	1971	71	538	0	609
1935	66,419	135	0	66,554	1972	49	590	0	639
1936	45,605	43	0	45,648	1973	25	478	0	503
1937	27,641	85	0	27,725	1974	61	246	0	307
1938	36,218	119	0	36,337	1975	131	312	0	443
1939	36,700	234	0	36,934	1976	298	123	0	421
1940	54,660	196	0	54,856	1977	9,220	1,163	0	10,383
1941	35,456	112	0	35,568	1978	21,520	2,256	0	23,776
1942	23,838	112	0	23,950	1979	35,823	3,053	0	38,876
1943	34,117	112	0	34,228	1980	38,188	2,668	0	40,856
1944	37,947	112	0	38,057	1981	42,450	1,401	0	43,851
1945	24,366	112	0	24,477	1982	35,019	1,684	0	36,703
1946	24,438	112	852	25,400	1983	35,454	1,481	135	37,069
1947	21,082	345	1,263	22,690	1984	45,572	1,445	128	47,145
1948	17,865	479	515	18,859	1985	40,514	1,105	2,581	44,200
1949	22,576	225	1,352	24,153	1986	46,557	1,020	4,882	52,458
1950	14,810	142	2,029	16,980	1987	41,212	1,334	2,081	44,628
1951	15,204	99	1,321	16,623	1988	43,991	871	4,882	49,745
1952	9,347	148	1,052	10,547	1989	38,637	639	13,383	52,659
1953	3,403	118	1,178	4,697	1990	39,850	1,126	35,757	76,732
1954	11,519	700	5,681	17,900	1991	32,162	1,190	17,445	50,798
1955	10,573	338	9,799	20,710	1992	19,699	779	24,338	44,815
1956	22,686	259	10,725	33,668	1993	12,680	623	7,739	21,041
1957	28,143	365	2,035	30,541	1994	10,043	1,009	13,318	24,370
1958	12,541	327	449	13,317	1995	8,667	1,042	4,821	14,530
1959	17,056	213	495	17,764	1996	10,287	708	5,604	16,598
1960	16,697	191	2,982	19,868	1997	20,615	1,003	12,477	34,095
1961	20,008	274	5,965	26,246	1998	20,073	465	50,726	71,264
1962	22,036	280	3,231	25,546	1999	9,527	201	10,168	19,896
1963	18,254	352	7,966	26,571	2000	23,206	259	7,182	30,647
1964	12,169	243	8,618	21,029	2001	7,785	561	4,078	12,424
1965	3,198	365	7,615	11,177	2002	4,536	276	7,963	12,775

Figure 1. Pacific mackerel landings for calendar years 1929 to 2002.

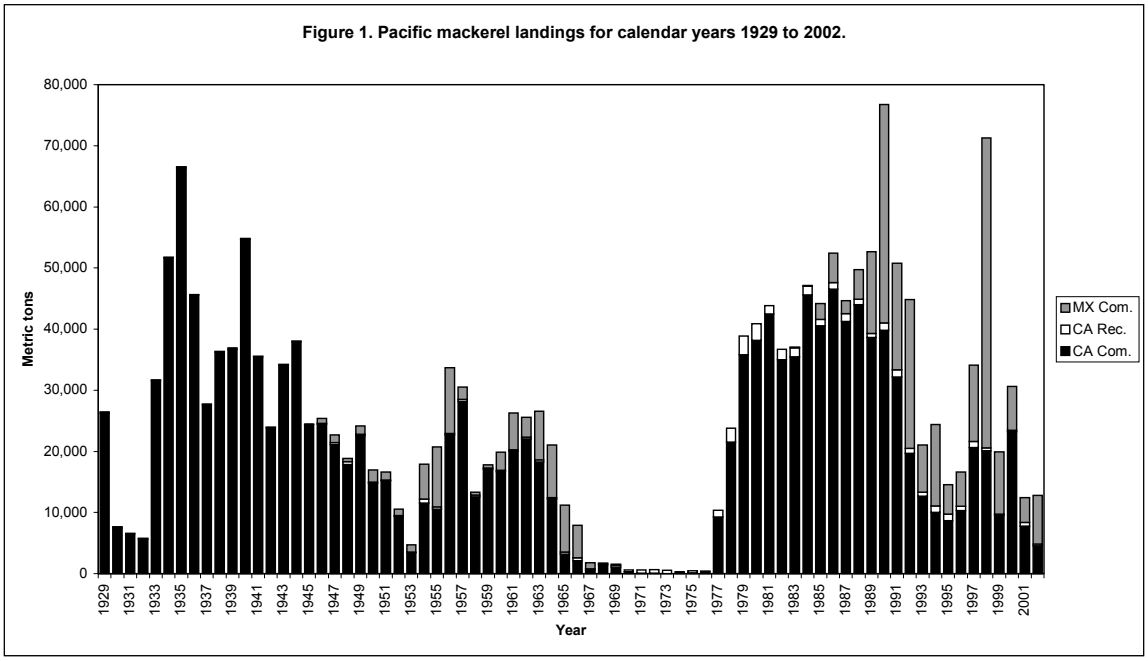

Figure 2. Proportional catch-at-age for California's commercial mackerel fishery, 1983-2002. The assessment model includes data from 1929-2002.

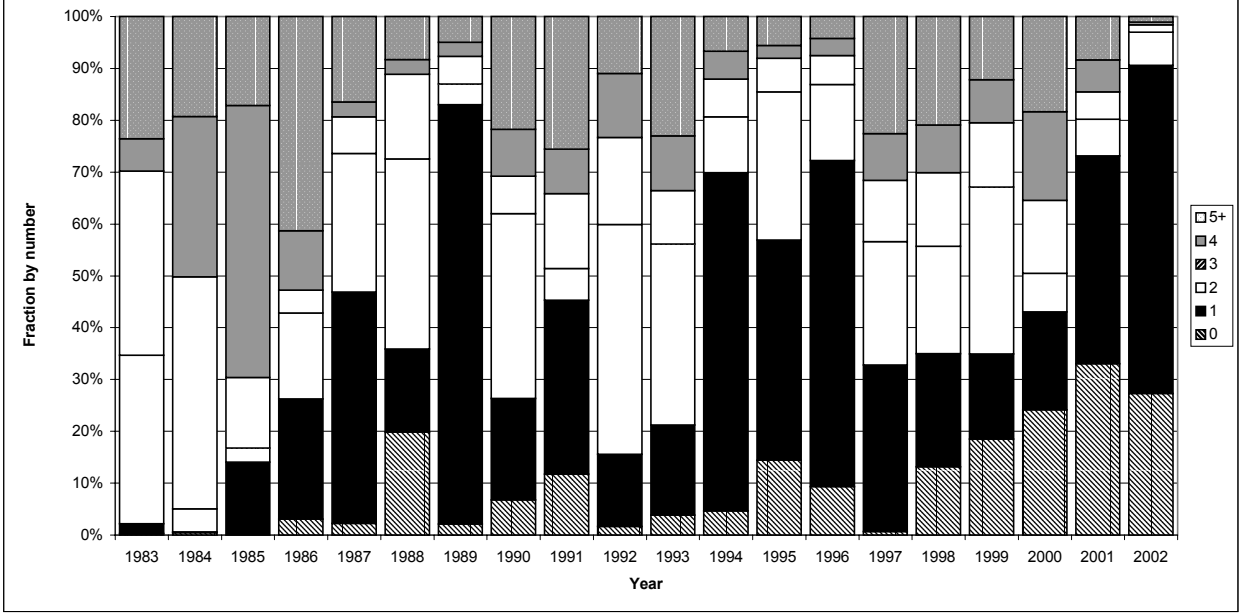

Figure 3. Mean weight-at-age of Pacific mackerel from California's commercial fishery, 1983-2002. The assessment model includes data from 1929 to 2002.

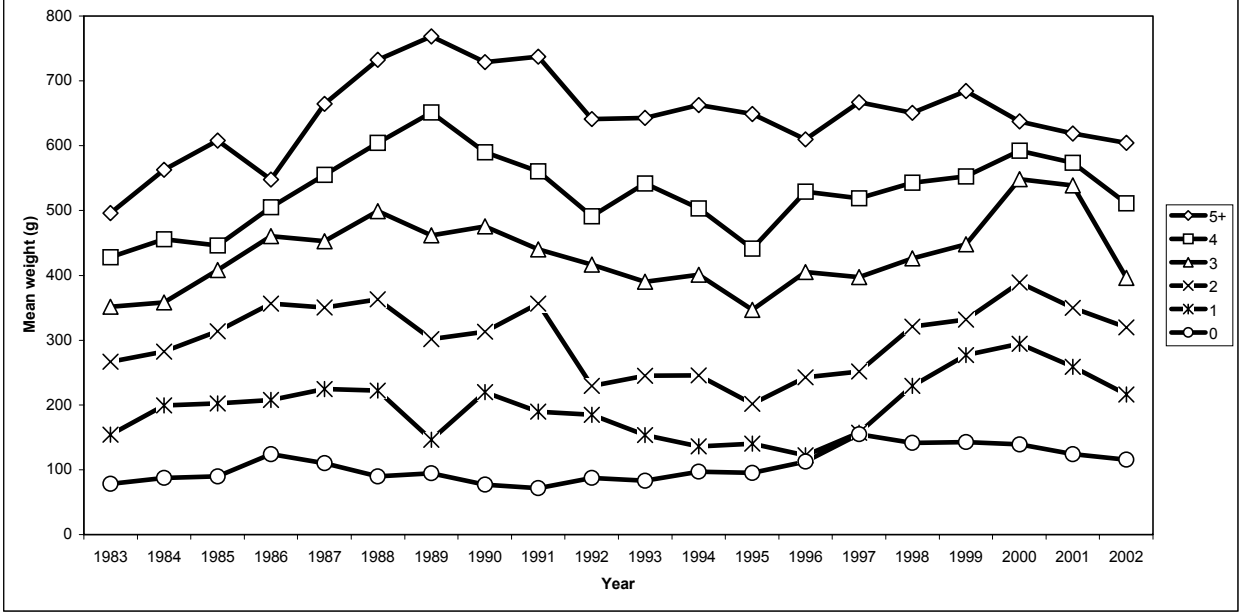

Figure 4. Aerial spotter index of relative abundance.

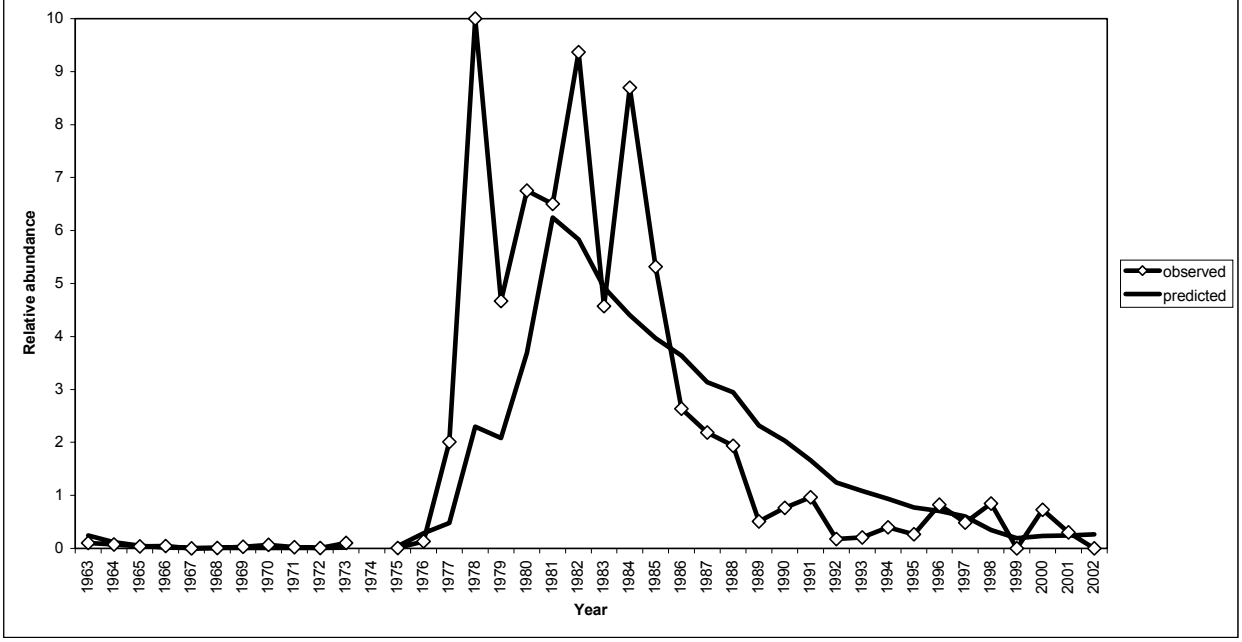

Figure 5. CalCOFI Index - proportion bongo tows positive for Pacific mackerel larvae.

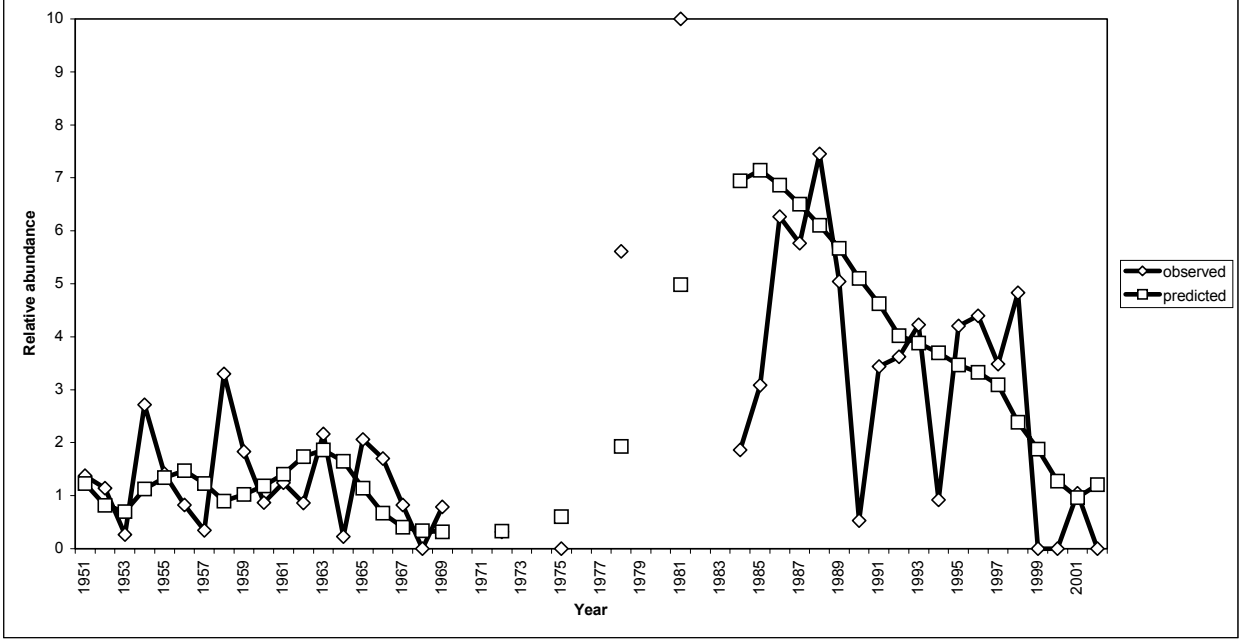

Figure 6. Southern California CPFV CPUE index.

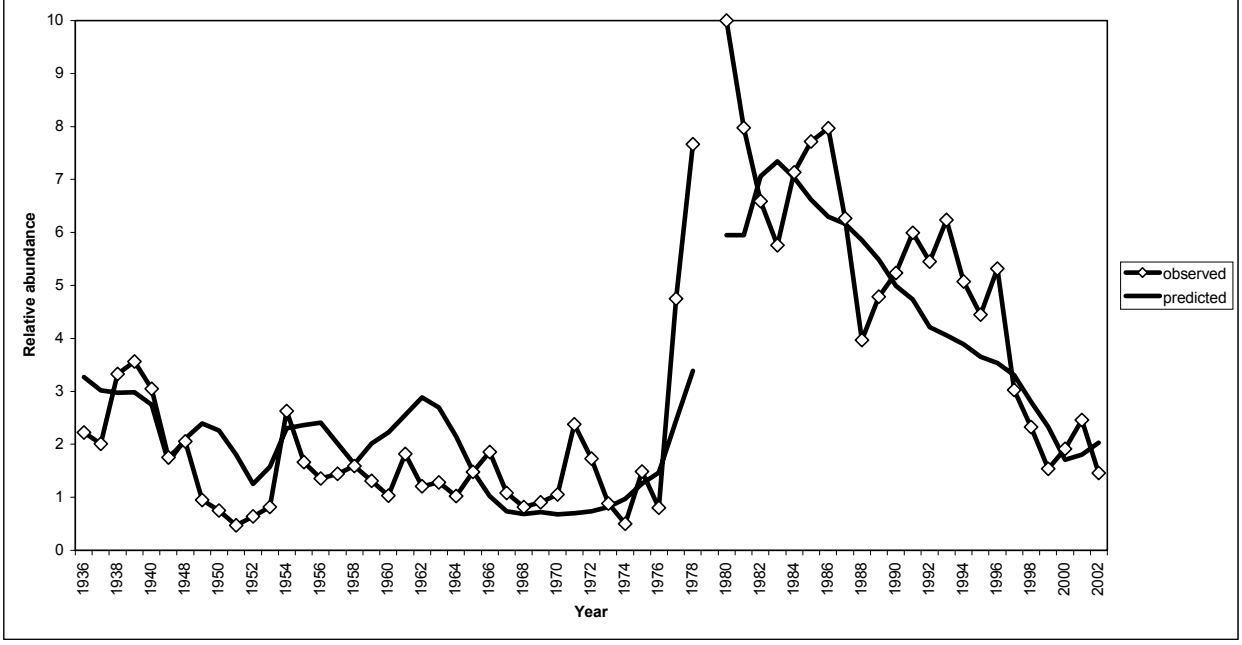

Figure 7. Northern California CPFV CPUE Index.

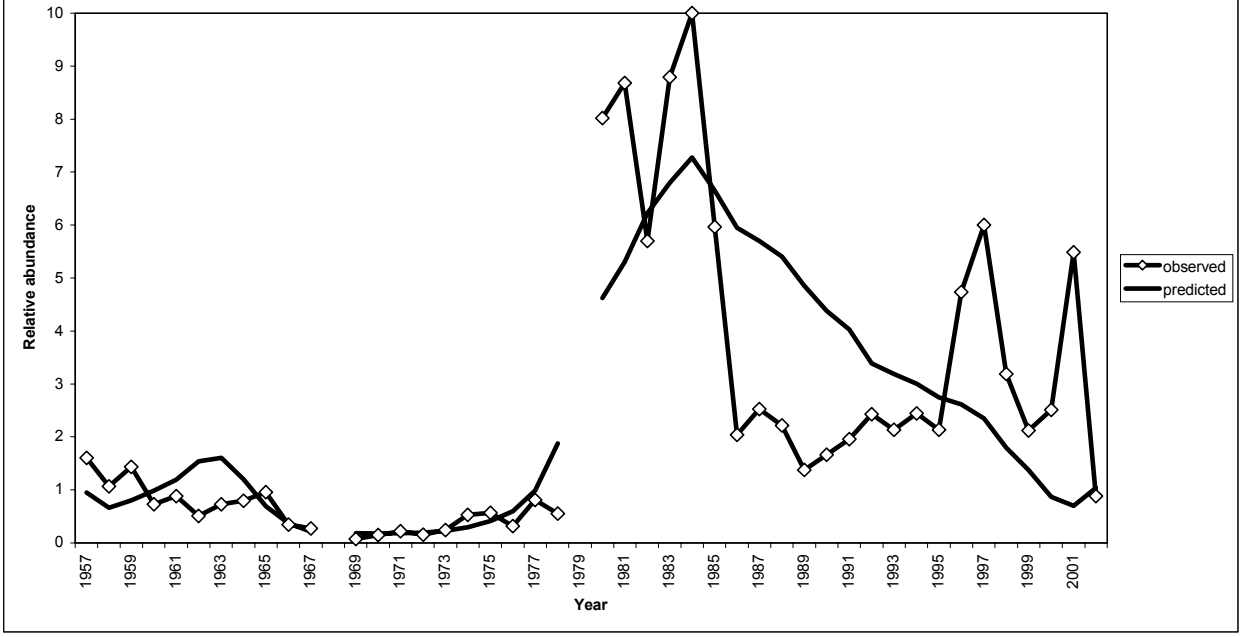

Figure 8. Relative abundance of Pacific mackerel in the trienniel shelf survey, Pt. Conception to US-Canada border.

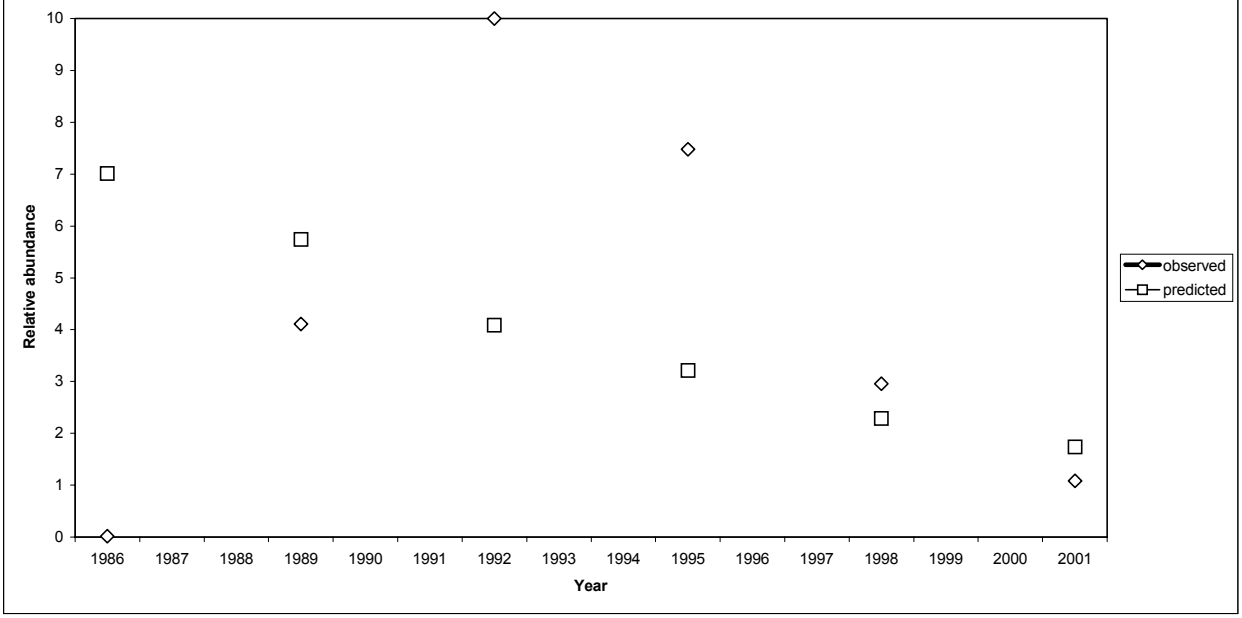

Figure 9. Pacific mackerel impingement at San Onofre Nuclear Generating Station. Index downweighted to lambda=0.1.

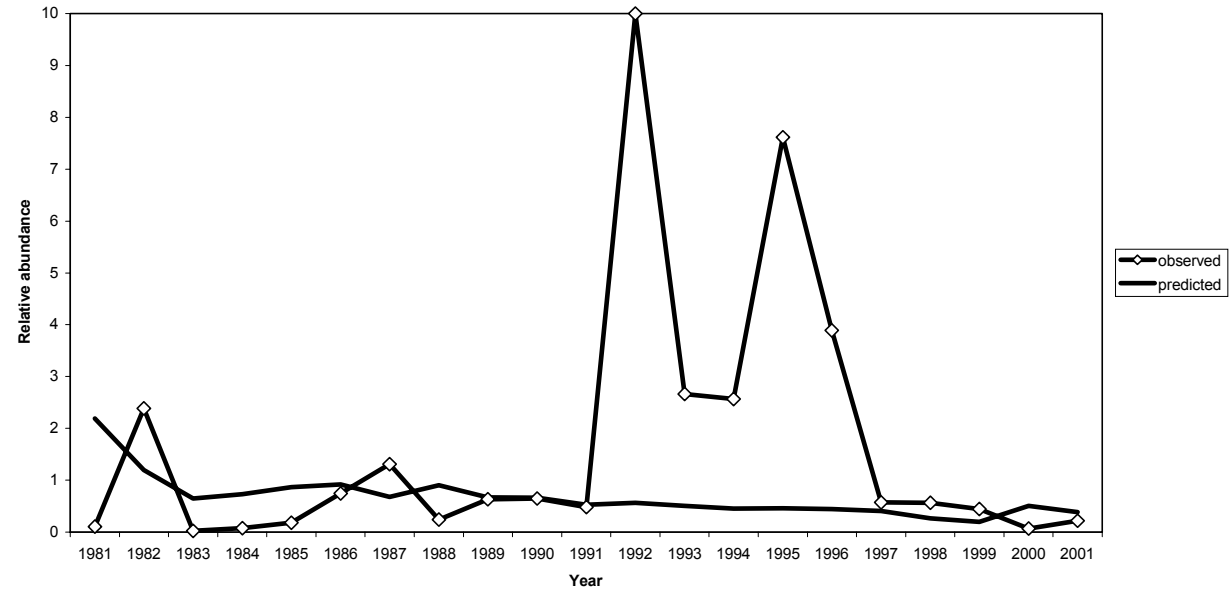

Figure 10. Year class abundance, January 1.

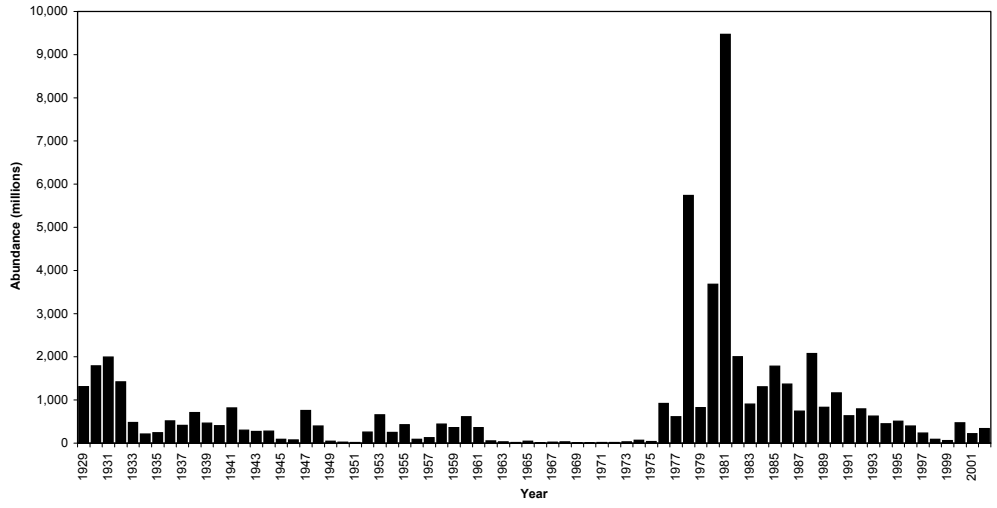

Figure 11. Relative reproductive success of Pacific mackerel, 1930-2002.

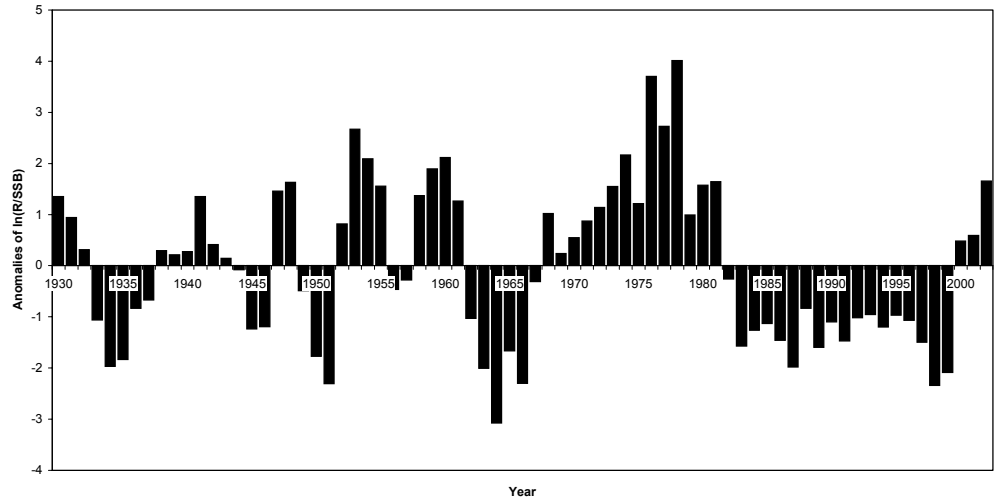

Figure 12. Spawning stock biomass and recruitment, 1982/83 through 2001/02.

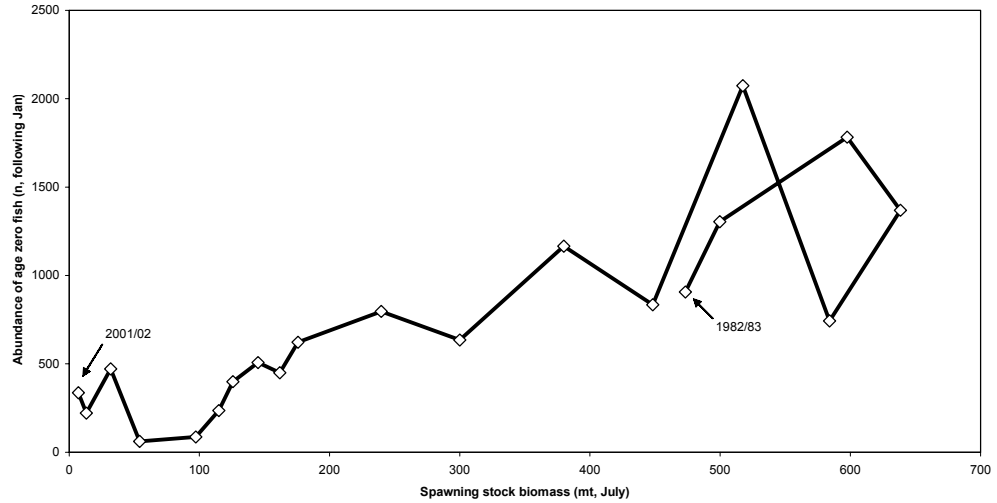

Table 3. Historical July 1 estimates of Pacific mackerel biomass (age 1+, metric tons) and recruitment (age 0, number $1x10^6$) estimated using the ADEPT model. See also Figures 10 and 13.

Year	Age 1+ Biomass (metric tons)	Recruits (millions)	Year	Age 1+ Biomass (metric tons)	Recruits (millions)
1929	155,896	1020	1966	4,765	6
1930	223,033	1392	1967	1,876	10
1931	296,408	1552	1968	1,696	15
1932	365,252	1106	1969	2,127	6
1933	350,660	373	1970	1,602	7
1934	289,642	167	1971	1,763	9
1935	192,454	187	1972	2,072	13
1936	127,778	399	1973	2,894	21
1937	114,806	319	1974	4,834	51
1938	105,650	549	1975	10,955	31
1939	116,944	363	1976	13,787	719
1940	91,214	312	1977	91,885	474
1941	86,466	635	1978	159,887	4466
1942	114,291	233	1979	518,344	640
1943	105,889	210	1980	684,946	2868
1944	84,429	217	1981	797,776	7372
1945	65,560	68	1982	1,394,964	1562
1946	41,260	57	1983	1,255,031	706
1947	20,911	582	1984	1,088,583	1015
1948	57,101	311	1985	940,048	1388
1949	60,937	35	1986	849,370	1064
1950	42,660	15	1987	787,238	576
1951	22,102	10	1988	657,432	1601
1952	8,371	199	1989	576,342	648
1953	26,419	497	1990	493,058	902
1954	61,973	193	1991	429,107	487
1955	55,240	328	1992	297,224	620
1956	62,799	66	1993	267,186	484
1957	33,036	98	1994	233,221	348
1958	21,457	332	1995	186,979	389
1959	44,194	282	1996	171,115	306
1960	51,912	473	1997	147,083	184
1961	81,419	266	1998	96,716	53
1962	97,143	41	1999	51,965	43
1963	70,707	25	2000	22,252	358
1964	36,733	10	2001	57,070	165
1965	13,080	26	2002	54,006	254
		Forecast for July 1 ==>	**2003**	**68,924**	---

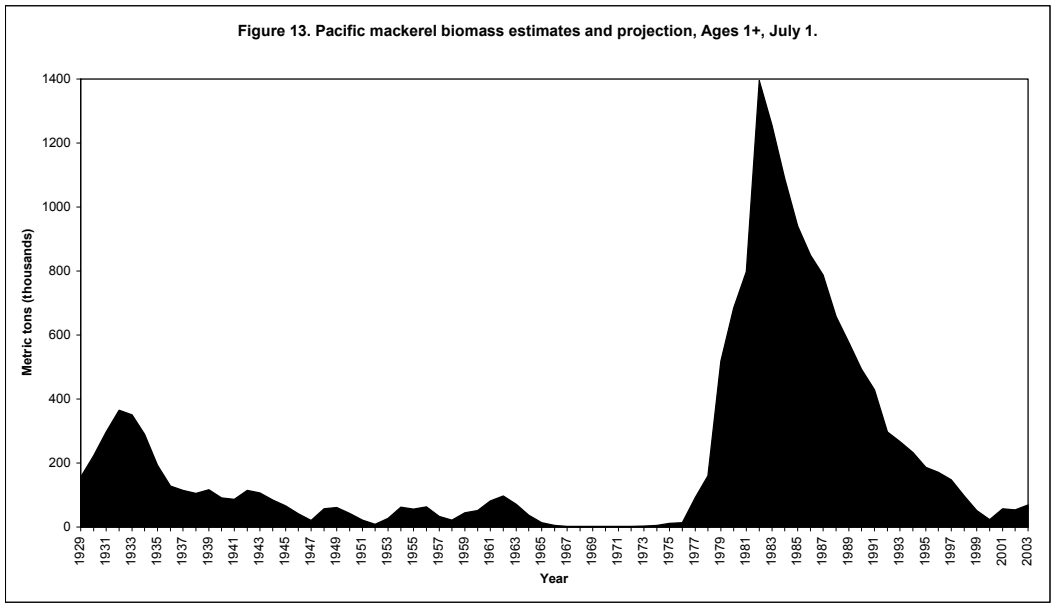

Table 4. Commercial landings (California directed fishery) and quotas (92/93 to 98/99) or harvest

guidelines (99/00 to present) for Pacific mackerel. See also Figure 14.

Season	Quota/HG (MT)	Landings (MT)
92/93	34,010	18,307
93/94	23,147	10,793
94/95	14,706	9,372
95/96	9,798	7,615
96/97	8,709	9,788
97/98	22,045	23,413
98/99	30,572	19,578
99/00	42,819	6,732
00/01	20,740	20,937
01/02	13,837	8,436
02/03*	12,535	*3,378*
03/04**	***10,652***	---

* landed as of 30 Apr 2003

** proposed harvest guideline

Figure 14. Pacific mackerel quotas (CA, pre-99/00) and harvest guidelines (PFMC, 99/00 onward), and resultant landings for each management season. The proposed HG for 2003/04 is 10,652 mt.